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A Method and Device for the Mitigation of CDMA Cross-Correlation Artifacts and the Improvement of Signal-to-Noise Ratios in TDMA Positioning Signals

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The present invention discloses a method and device for the mitigation of pseudorandom code cross-correlation artifacts and the improvement of signal to noise ratios in CDMA positioning signals that are pulsed in a TDMA scheme to mitigate the near/far problem. The present invention has particular, but not exclusive application in positioning technologies where precise range measurements free from cross-correlation artifacts are essential for accurate positioning.

Background to the Invention

Radiolocation systems utilize multiple transmitters each transmitting a unique code division multiple access (CDMA) signal. A CDMA receiver generally tracks these signals using a plurality of channels, each comprising two or more correlators to determine the range to each of the transmitters. Range can also be determined using mathematically similar techniques such as convolution, matched filtering, or Fast Fourier Transforms (FFTs). Traditional CDMA receivers continuously correlate against these continuous CDMA signals.

Some radiolocation systems transmit CDMA ranging signals in a pulsed time division multiple access (TDMA) scheme to mitigate the so-called near/far problem. Cross-correlation values and signal to noise ratios (SNR) are severely compromised when a receiver continuously correlates against these pulsed TDMA signals. When a CDMA receiver continuously correlates against a pulsed signal, a portion of the correlation time does not include the desired signal. During these off pulsed times, the CDMA receiver is correlating against other pulsed CDMA signals and noise, not the desired signal. When the receiver correlates continuously against these pulsed signals, the cross-correlation value between the CDMA signals is higher than if the signals were not pulsed. For example, range biases of up to 30 metres are evident on cross-correlation affected pseudoranges when using 1.023MHz Gold codes pulsed at a 20% duty cycle. Further, received SNR values are decreased by at least 10dB when pulsing with a 10% duty cycle.

Prior art single channel CDMA correlator receivers work with continuously transmitted CDMA signals and therefore do not have any requirement to synchronize to a network TDMA pulsing

scheme. These receivers change the correlated CDMA code based on internal receiver requirements, such as measurement updates and management of decoding navigation data.

Prior art single channel CDMA correlator receivers do not mitigate cross correlation artifacts in pulsed TDMA ranging signals, nor do they improve received SNR values. Therefore, a system which mitigates cross-correlation artifacts and improves SNR in received TDMA positioning signals is highly desirable. Additionally, reducing and reusing receiver resources is also highly desirable.

Disclosure of the Invention

The present invention discloses a method and device to mitigate CDMA cross-correlation artifacts and improve signal to noise ratios in pulsed TDMA ranging signals by configuring a single channel position receiver to correlate on a specific unique CDMA positioning signal only during the TDMA pulse periods of the respective unique CDMA positioning signal transmissions. The receiver is configured to chronologically synchronize its single channel correlator circuitry with a plurality of Time Division Multiple Access (TDMA) positioning-unit device transmissions. The TDMA synchronization is controlled by a deterministic algorithm based on knowledge of the network TDMA sequence, positioning-unit device locations, and network time.

A plurality of chronologically synchronized positioning-unit devices, positioned at known locations, transmit positioning signals in a predetermined TDMA sequence, such that each transmitter has a unique transmission time slot. A position receiver is configured to receive TDMA positioning signals from the network of positioning-unit devices and determine position, velocity and network time. In a simplified position receiver, the position receiver is configured with a single receive channel capable of receiving only one positioning signal at a time. This single receive channel incorporates a plurality of CDMA correlators, capable of correlating on successive pulse transmitted CDMA codes in synchronization with the network TDMA sequence. CDMA correlators that synchronously adapt to the TDMA transmissions of the network of positioning devices are referred to as TDMA correlators to distinguish them from traditional CDMA correlators.

The TDMA correlation is controlled by a deterministic algorithm based on knowledge of the TDMA sequence, TDMA timing from each positioning-unit device, positioning-unit device locations, and network time. The TDMA correlator internal PRN code generator (and other associated tracking values) is synchronously updated to follow the TDMA sequence of each positioning-unit device transmission, such that the single channel position receiver is always correlating on the correct PRN code of the current transmitting positioning-unit device. As the position receiver location

changes the deterministic algorithm considers the change in propagation delay from each positioning-unit device and adjusts the TDMA correlator time-slot synchronization to best fit the positioning-unit device transmissions.

A network of chronologically synchronized positioning-unit devices transmit CDMA positioning signals in a TDMA scheme to a position receiver. The position receiver incorporates a single receive channel, which incorporates a plurality of TDMA correlators. The position receiver initializes a global search and acquires a single unique CDMA positioning signal transmitted from one of the positioning-unit devices in-view. The position receiver interrogates navigation data transmitted from the acquired positioning-unit device to determine positioning-unit device transmission time and TDMA pulse sequence. The navigation information also provides information on other positioning-unit devices in-view and their respective CDMA codes and TDMA transmission sequences (i.e. their transmission time slots). The position receiver synchronizes its plurality of TDMA correlators to the acquired positioning-unit device signal, such that the receiver is only correlating on the acquired positioning signal when the acquired positioning-unit device is transmitting. The position receiver subsequently successively searches and acquires other positioning-unit device signals from their known CDMA codes and TDMA slots.

From the navigation data received from the first acquired positioning-unit device the position receiver determines which positioning-unit device will transmit the next positioning signal. The position receiver stores the current tracking values for the first acquired positioning-unit device, allocates the appropriate PRN code and initial tracking values to the TDMA correlators for the second positioning-unit device, and subsequently acquires and tracks the second positioning-unit device signal at the commencement of its transmission. The position receiver then determines which positioning-unit device will transmit the third positioning signal, and allocates the appropriate PRN code and initial tracking values to the TDMA correlators. The position receiver subsequently acquires and tracks the positioning-unit device at the commencement of its transmission. This process is repeated through all available TDMA slots. When the TDMA sequence returns to the first positioning-unit device the stored first positioning-unit device tracking values are reloaded into the TDMA correlators and tracking of the first positioning-unit device is recommenced at the beginning of its next pulse transmission. This process is repeated through all available TDMA slots.

An alternative method of sequencing through a block of TDMA time slots is to pre-set the tracking values that will be used for the block of TDMA time slots. At the completion of that block, the TDMA correlators are reconfigured for the next block of TDMA time slots. A block of TDMA time

slots contains one or more separate TDMA time slots. Each time slot contains zero or more CDMA ranging signal.

Accurate location and time can now be determined by the position receiver by performing a position, velocity and time (PVT) solution while the single channel TDMA correlators are chronologically synchronized with the network TDMA scheme. A significant improvement in received SNR is observed due to the TDMA correlators only integrating on a particular CDMA code when the respective transmitter is transmitting. That is, the TDMA correlators do not integrate unwanted noise and other CDMA codes when the transmitter of interest is not transmitting. Furthermore, cross-correlation artifacts are significantly mitigated, or eliminated entirely due to the TDMA correlators not integrating CDMA codes that are transmitted from other positioning-unit devices.

Correlator Configuration

In the preferred embodiment a TDMA correlator is configured to integrate and dump at least once every TDMA pulse period. This allows correlator re-use at a speed determined by the TDMA transmission scheme. For example, in one embodiment of the present invention a 1023 chip Course/Acquisition CDMA code is transmitted at a rate of 1.023 MHz. This represents a code sequence duration of 1 millisecond. The TDMA scheme pulses each CDMA transmitter in a pseudorandom manner such that 93 chips of each code are transmitted from each transmitter in any given millisecond period. This provides eleven TDMA time slots for a network of chronologically synchronized positioning-unit devices, and represents an approximate 9% transmission duty cycle from each transmitter. The transmission pulse periods can vary in duration and also vary in frequency, so long as the sum of all pulses equals the prescribed duty cycle for any given one millisecond period. For example, the pulsing scheme could pulse 20 chips followed by a 100 chip pause, followed by the remaining 73 chips in one given millisecond. Then in the next millisecond period pause 100 chips, pulse 40 chips, pause 200 chips, pulse 30 chips, pause 300 chips, and pulse the remaining 23 chips. Therefore, a TDMA pulse period could be as short as practicable (twenty chips in this example), or as long as the duty cycle allows, in this case 93 chips (approximately 91 microseconds). The TDMA correlators must therefore operate with a variable integration and dump period, with the period being governed by the duration of the current received TDMA pulse period.

The single channel TDMA correlators must also be able to store current tracking values at the end of a pulse period and re-initialize previously stored tracking values for the next transmitted positioning signal, such that continuous tracking of a plurality of synchronous positioning-unit

device signals can be achieved. Previously stored tracking values include predicted changes in tracking values from the time they were stored until the time they are re-initialized in the TDMA correlators. For example, the measurement of integrated carrier phase requires the number of zero crossings of a DCO carrier phase to be counted for each measurement period. A TDMA correlator of the present invention does not count zero crossings of a DCO which is "free wheeling" between transmission pulses, as does a prior-art correlator tracking pulsed positioning signals. Therefore, a TDMA correlator must predict how many zero crossings will occur between pulses based on the current DCO value and DCO rate value. This prediction can be readily achieved because the time interval between TDMA pulses of any one transmitter is accurately known. The stored tracking values for the previous pulse of a particular transmitter are updated with the predicted tracking values and subsequently provided to each TDMA correlator for re-initialization when the next pulse from the particular transmitter is received. Stored tracking values include PRN code number, PRN code delay, carrier digital controlled oscillator (DCO) values, PRN code DCO values, integrated carrier phase values, correlation values, and TDMA pseudorandom sequence values. Alternate embodiments include integrated and dump techniques that utilize a block of TDMA time slots.

Acquisition of TDMA positioning signals

A position receiver determines coarse network time by performing a time measurement from at least one positioning-unit device. In the preferred embodiment, time within ten microseconds will be adequate for initial coarse TDMA slot alignment. During acquisition of the first positioning-unit device signal the single channel TDMA correlators are configured to integrate over the complete code sequence period. This allows fast acquisition of the first positioning-unit device when network time and TDMA pulse sequences are unknown. Once coarse time alignment is achieved using the first acquired positioning-unit device, the single channel TDMA correlators revert to synchronized mode. Synchronized mode successively searches, acquires, and tracks all positioning devices in-view from information acquired from the first positioning-unit device. The first positioning-unit device passes information regarding the PRN codes and TDMA time slots of all nearby positioning-unit devices to the roving position receiver. The roving position receiver uses this information to synchronize its TDMA correlators to the network TDMA scheme and quickly acquire and track all positioning-unit devices in-view.

TDMA Determination

The TDMA pulse sequence of each positioning-unit device is transmitted in its navigation message, and also passed to other positioning-unit devices in-view to be transmitted from their

navigation messages. The position receiver determines TDMA sequences of all positioning-unit devices in-view by interrogation of the navigation message from at least one positioning-unit device.

Alternatively, the TDMA pulse sequence may be associated with the positioning-unit device PRN code. In this embodiment the position receiver determines TDMA sequence by associating a received PRN code with a predetermined TDMA sequence. This allows fast TDMA correlator synchronization with the acquisition of the first positioning-unit device. Subsequent positioning-unit device codes and time slots are then determined by interrogation of the acquired positioning-unit device's navigation message.

Chronological Synchronization

The knowledge of coarse network time and TDMA sequence allows the position receiver to chronologically synchronize the single channel TDMA correlators with all positioning-unit device TDMA transmissions in-view. As more positioning-unit devices are acquired network time can be determined more accurately. With at least three positioning-unit devices acquired, a single-point position (PVT) solution can be determined, which gives network time to the nanosecond level.

TDMA Pulse Sequence

Each positioning-unit device pulses its CDMA transmission in a TDMA sequence. In one embodiment a 100 microsecond pulse is transmitted every 1 millisecond from each positioning-unit device. This gives a 10% pulse duty cycle with 10 available slots. The position receiver interrogates at least one positioning-unit device navigation message to determine the respective TDMA slot positions of all positioning-unit devices in-view.

Propagation Delay

As the distance between a positioning-unit device and a roving position receiver increases the propagation delay of the transmitted signal increases accordingly. This leads to the TDMA pulse transmission of the positioning-unit device not being received entirely in the time slot allocated by the roving position receiver. This is of no consequence when all positioning-unit devices are equidistant from a roving position receiver. However, when positioning-unit devices vary significantly in distance from a position receiver overlaps in TDMA transmissions may occur. As the position receiver location changes a deterministic algorithm considers the propagation delay from each positioning-unit device and adjusts the TDMA correlator synchronization to best fit the positioning-unit device transmissions. This requires the dynamic adjustment of TDMA time slot position and duration depending on position receiver location. For example, a position receiver is

located 10 kilometres from a first positioning-unit device and 100 metres from a second positioning-unit device. The propagation delay from the first device is in the order of 30 microseconds, whereas the propagation delay from the second device is in the order of 300 nanoseconds. If these two devices are pulsing in adjacent 100 microsecond TDMA time slots, with the first devices' pulses preceding the second devices' pulses, the position receiver will experience a pulse overlap of approximately 29.7 microseconds. In this example, given for illustrative purposes, the position receiver may adjust its slot positions and durations so as to:

1. Delay the first device TDMA slot by 30 microseconds and truncate 29.7 microseconds from the tail of the first time slot, such that the next (closer) CDMA code is correlated in full.
2. Delay the first device TDMA slot by 30 microseconds and truncate 29.7 microseconds from the head of the next time slot, such that the current (distant) CDMA code is correlated in full.
3. Delay the second device TDMA slot by 300 nanoseconds and truncate 29.7 microseconds from the head of the second time slot. Also, delay the first device TDMA slot by 30 microseconds and truncate 29.7 microseconds from the tail of the first time slot, such that all overlap between the two CDMA codes is eliminated.
4. Delay the second device TDMA slot by 300 nanoseconds and truncate 14.7 microseconds from the head of the second time slot, and also delay the first device TDMA slot by 30 microseconds and truncate 15 microseconds from the tail of the first time slot, such that the overlap period is shared between the two CDMA codes. That is, switch TDMA slots in the middle of the overlap of the two signals.

Alternatively, the overlap problem can be rectified in a further embodiment of the present invention by providing a position receiver with a plurality of receive channels incorporating TDMA correlators. As two pulses overlap two channels can simultaneously track both CDMA codes, provided any near/far constraints can be overcome. A plurality of receive channels incorporating TDMA correlators also provides the capability to track multiple CDMA codes that are transmitted in the same slot.

Conclusion

When TDMA correlator synchronization is achieved in a roving position receiver, a significant improvement in received SNR is observed from each positioning-unit device and cross-correlation artifacts are significantly reduced. A roving position receiver can determine high accuracy single point (PVT) solutions due to the elimination of these cross-correlation artifacts and the improved reception of high signal-to-noise ratio positioning signals. An additional benefit is the reduction in

receiver circuitry required to produce a single channel position receiver incorporating a TDMA correlator system. This produces benefits such as decreased receiver complexity, a reduction in receiver power consumption, a reduction in receiver size, and ultimately a reduction in receiver cost.

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